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PROBABILISTIC CONSEQUENCE ASSESSMENT OF HYDROGEN SULPHIDE RELEASES FROM A HEAVY WATER PLANT: SENSITIVITY STUDY OF SULPHUR DIOXIDE TOXICITY

by

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ABSTRACT

This study investigates the sensitivity of the probabilistic consequences projected by the computer code GASPROB to changes in the assumed toxicity of sulphur dioxide gas (SO_2). GASPROB simulates the consequences of accidental releases to the atmosphere of hydrogen sulphide (H_2S) at a heavy water plant.

Five combinations of different LC50 and LC10 functions (lethal concentration versus exposure time) were tested, each varying over 3 orders of magnitude. The results indicate a distinct sensitivity to both the LC50 and LC10 functions.

RÉSUMÉ

Le présent rapport rend compte de l'étude de sensibilité des conséquences probabilistes projetées par le code machine GASPROB par rapport aux changements de la toxicité supposée du bioxyde de soufre (SO_2) gazeux. Le code machine GASPROB simule les conséquences de rejets accidentels d'hydrogène sulfuré (H_2S) dans l'atmosphère en provenance d'une usine d'eau lourde.

Cinq combinaisons de différentes fonctions de CL 50 et de CL 10 (concentrations létales par rapport au temps d'exposition) ont été mises à l'essai, chacune s'étalant sur trois ordres de grandeur. Les résultats indiquent une nette sensibilité des deux fonctions CL 50 et CL 10.

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A. INTRODUCTION

This report is concerned with the sensitivity of the computer code GASPROB to the assumed toxicity of sulphur dioxide gas (SO_2). GASPROB was developed to simulate the consequences of accidental releases to the atmosphere of hydrogen sulphide (H_2S) at a heavy water plant. It includes simulations of initial gas behaviour, such as gravitational settling of a cold release and the rise of the resulting jets and flares if the H_2S were ignited and burned to SO_2, subsequent atmospheric dispersion under a range of possible weather conditions, and the toxic effects on the exposed population. The code uses, as input, the site-specific dispersion climatology, topography and population distribution, and probabilistic lethal dose data for the released gas (H_2S or SO_2). The output for a given initiating event can include ground level gas concentrations around the plant, projected numbers of fatalities within specified areas and the projected total fatalities regardless of location, each with an associated probability. The development of GASPROB and the code itself are described in two earlier reports prepared for the Atomic Energy Control Board (AECB) (Refs. 1 and 2).

A third report (Ref. 3), which was recently prepared for the AECB, presented the numerical results of a series of sensitivity tests carried out on the GASPROB code to determine the dependence of the projected fatalities on certain input parameters and assumptions implicit in the code. This report also gave the results of 43 full probabilistic consequence analyses for the Bruce heavy water plant, which included a range of postulated initiating events, i.e., pipe breaks of various sizes, with and without ignition of the release, and H_2S storage tank failures. The sensitivity tests investigated the effects on the curves of probability versus number of fatalities of such parameters as the model grid size, the dispersion climatology, the initial cloud density (for a storage tank failure) and building wakes.

Also included was a test of the sensitivity to changes in the assumed toxicity curves (LC10 and LC50 as functions of exposure time) for H2S.

The present study investigates the sensitivity of the probabilistic consequences projected by GASPROB to changes in the assumed LC10 and LC50 curves for SO2. The study is designed to provide an estimate of the likely "error band" of consequence probabilities due to this sensitivity for a large, burning release of SO2 simulated in earlier work (see Run 8 in Ref. 3). The results of the earlier simulation are reproduced in this report as Figure 1. As before, the study is specific to the Bruce heavy water plant. Chapter B of this report (Methodology) provides details of the initiating event, the SO2 toxicity functions selected for the test and other inputs used in running the GASPROB model. The results are presented in Chapter C, together with a discussion of their significance. Finally, Chapter D summarizes the work done and the conclusions drawn.

B. METHODOLOGY

1. Initiating Event

In order to explore the potential upper bound of the consequences of a burning release, the initiating event chosen for this study was the one involving an SO2 release which, in the previous simulations (see Ref. 3), resulted in the highest expected number of fatalities. This event involves a single-ended 1300 mm diameter pipe break at a height of 10 m above ground level with no isolation of the affected process tower. The H2S flow rates from the break were presented in Ref. 3, and are reproduced in Table 1 of this report. Note that the corresponding SO2 flowrates are approximately twice the values shown for H2S.

2. SO2 Toxicity Functions

The base case lethal dose (concentration versus exposure time) functions used in this study are illustrated in Figure 2a. The

base case is defined by the LC50 function having a value of 25 000 mg/m³ (10 000 ppm) at exposure times of 10 seconds or less and an LC10 function with a value of 5 000 mg/m³ (2 000 ppm) at 10 seconds or less. The functions approximate the slope of the lethal dose curves projected by Engelhart and Holliday (Ref. 4), although the concentration values of the base case and the other cases tested do not correspond to the original curves. The functions were selected in consultation with the authors of Ref. 4, such as to cover the likely range of uncertainty, or error bands, associated with the original lethal dose curves projected in their report. Accordingly, the LC50 and LC10 functions were increased and decreased from the base case by an order of magnitude, both separately and in combination. The resulting five cases (including the base case) are defined in Table 2 in terms of their LC50 and LC10 values for exposure times of 10 seconds or less. The corresponding functions for longer exposure times are shown in Figures 2a - 2e. It should be noted that some combinations, where LC10's would be greater than LC50's, are physically impossible and are not included. Finally, it should also be noted that the four-step functions used here are not the same as the three-step functions used in earlier consequence assessments (Ref. 3). To improve the precision of the model, an additional step has been introduced at an exposure time of 120 seconds.

3. Other Inputs

Runs of the GASPROB code require the specification of a large number of model options and input parameters (see Ref. 2). The major options and inputs used in this study are summarized below. They are the same ones, applicable to a burning release, used in the full consequence assessments carried out earlier (Ref. 3).

a) The full grid model of the Bruce area was used, with the closest 18 nodes or elements subdivided into 9 sub-elements each.

b) Briggs' dispersion coefficients were used in the atmospheric modelling.

c) The effect of topographic relief was retained in the model.

d) The site-specific climatology developed earlier for the Bruce heavy water plant was used, although the lake breeze effect was not included.

e) The effect of building attenuation was not included.

Other details are provided in Table 3.

C. RESULTS AND DISCUSSION

The output from GASPROB consists of a frequency distribution (cumulative distribution function) of the number of fatalities projected by the simulation. The outputs from the five cases tested are presented in graphical form in Figure 3, in a similar form to the results of the sensitivity analyses conducted earlier on other parameters (see Ref. 3). In addition, Figure 4 shows the original consequence histogram from Run 8 of Ref. 3, upon which have been superimposed "error bands". These correspond to the largest and smallest probabilities for each interval (number of fatalities) which were determined in the sensitivity analysis.

The results indicate the following:

a) At the low end of the consequence scale (1 - 50 fatalities), the cumulative probabilities for all cases are quite similar, except for case (e), which assumed both a relatively high LC50 and relatively high LC10. In this latter case, the probabilities are significantly lower.

b) In the range of 100 - 1 000 fatalities, the results clearly fall into three groups, depending on the assumed LC10 function. Thus, cases (c) and (d) (LC10 for 10 seconds or less = 500 mg/m^3) gives the highest probabilities, and cases (a) and (b) (LC10 = 5 000 mg/m^3) give intermediate probabilities. The range of probabilities at 1 000 fatalities is about an order of magnitude.

c) The effect of the assumed LC50 functions is apparent only at the high end of the consequence scale (greater than 1 000 fatalities).

However, it rapidly becomes significant and results in, for example, a 2 to 3-fold difference in the cumulative probabilities at around 5 000 fatalities.

Also plotted on Figure 3 are the results of the corresponding full consequence run (Run 8) from the earlier study (Ref. 3). As discussed above, the step function approximations used here are not the same as those used earlier. As well, the LC50 and LC10 concentrations assumed in Ref. 3 do not correspond exactly to any of the cases considered here. However, there is a close similarity between case (e) and Run 8 of Ref. 3 (the LC50's for 10 seconds or less are identical and the LC10's for these exposure times differ only by a factor of 2). Not surprisingly, therefore, the results from the earlier study are close to the results from case (e). The lower LC10's assumed in Ref. 3 do, however, result in somewhat higher probabilities above about 100 fatalities.

D. CONCLUSION

This study has investigated the sensitivity of the probabilistic consequences simulated by the GASPROB code to assumed lethal dose functions (LC50's and LC10's) for SO2 which were varied over 3 orders of magnitude. The results are applicable only to the Bruce heavy water plant and may not be repeated if the simulation were performed for another site. They show a distinct sensitivity to both the LC50 and LC10 functions, although the sensititvity to LC10 appears to be most significant, e.g., an order of magnitude difference in cumulative probabilities above 1000 fatalities due to changes in the LC10, and a factor of 2 to 3 difference in probabilities above 5000 fatalities due to changes in the LC50. Since the initiating event was selected to produce relatively high expected fatalities, and since the lethal dose functions tested were chosen to cover the likely range of uncertainty in the lethal doses for SO2, the case which predicted the highest probability for any given number of fatalities (case (d)) provides an indication of the upper bound of consequences resulting from a burning H2S release.

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1. MONSERCO LIMITED: Probabilistic consequence assessment of hydrogen sulphide releases from a heavy water plant - scope determination. AECB Research Report No. INFO-0102-1, January 1983.

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3. MONSERCO LIMITED: Probabilistic consequence assessment of hydrogen sulphide releases from a heavy water plant - consequence assessments. AECB Research Report No. INFO-0102-3, March 1984.

4. ENGELHARDT, F.R. and M.G. Holliday: Dose-response relationships of acute exposure to SO2. AECB Research Report No. INFO-0041, May 1981.

5. MONSERCO LIMITED: The influence of short-term concentration peaks on exposure risks in the vicintiy of an episodic release of H2S. AECB Research Report No. INFO-0032, May 1981.

Time (sec)	Break Flow (Kg H2S/s)
0	5313
20	4328
40	3524
60	2870
100	1904
150	1140
200	682
250	408

TABLE 1 : BREAK FLOW RATES OF H2S FOR THE SELECTED INITIATING EVENT (1300 mm break, no tower isolation).

CASE	LETHAL CONCENTRATIONS FOR 10 SECS OR LESS			
	LC50		LC10	
	(mg/m^3 (ppm))		(mg/m^3 (ppm))	
(a - base case)	25 000	(10 000)	5 000	(2 000)
(b)	250 000	(100 000)	5 000	(2 000)
(c)	25 000	(10 000)	500	(200)
(d)	2 500	(1 000)	500	(200)
(e)	250 000	(100 000)	50 000	(20 000)

TABLE 2 : DEFINITION OF SO2 TOXICITY CASES USED IN SENSITIVITY TEST

Indoor/outdoor effect	Not considered
Dispersion coefficients	Briggs
Building wake effect	Not applicable
Terrain height modification	Included
Trapping effect	Included
Trapping height	500 m
Lake breeze effect	Not included
C, Aϕ. (building effect constants)	Not applicable
Atmospheric constant β *	4.0
Atmospheric constant C for stability 1-6*	9.2,9.2,9.2,2.8,0.92,0.92
Atmospheric constant a for stability 1-6*	1.0,1.0,1.0,1.0,1.0,1.0
Atmospheric constant ^{f}max for stability 1-6*	0.01,0.01,0.01,0.2,1.0,1.0
Episode duration time (sec) *	600

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* Required for H2S RISK sub-model (see reference 5)

β is the ratio of Lagrangian to Eulerian time scales.

C, a and ^{f}max are stability dependent parameters of the lateral wind velocity spectrum.

TABLE 3 : SUMMARY OF GASPROB OPTIONS AND INPUTS USED IN THIS STUDY

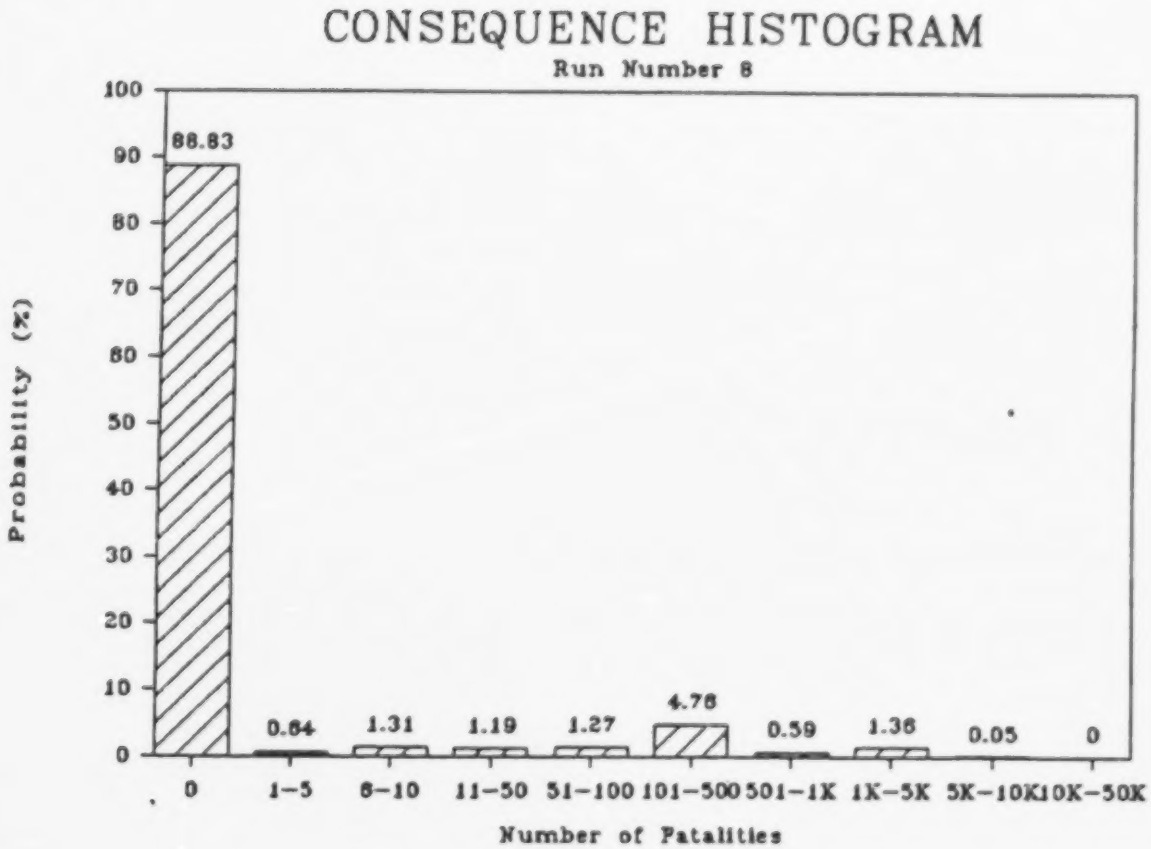


FIGURE 1: CONSEQUENCE HISTOGRAM FOR BURNING RELEASE OF S02 FROM SINGLE-ENDED 1300 MM PIPE BREAK (LOW LEVEL, NO PROCESS TOWER ISOLATION)

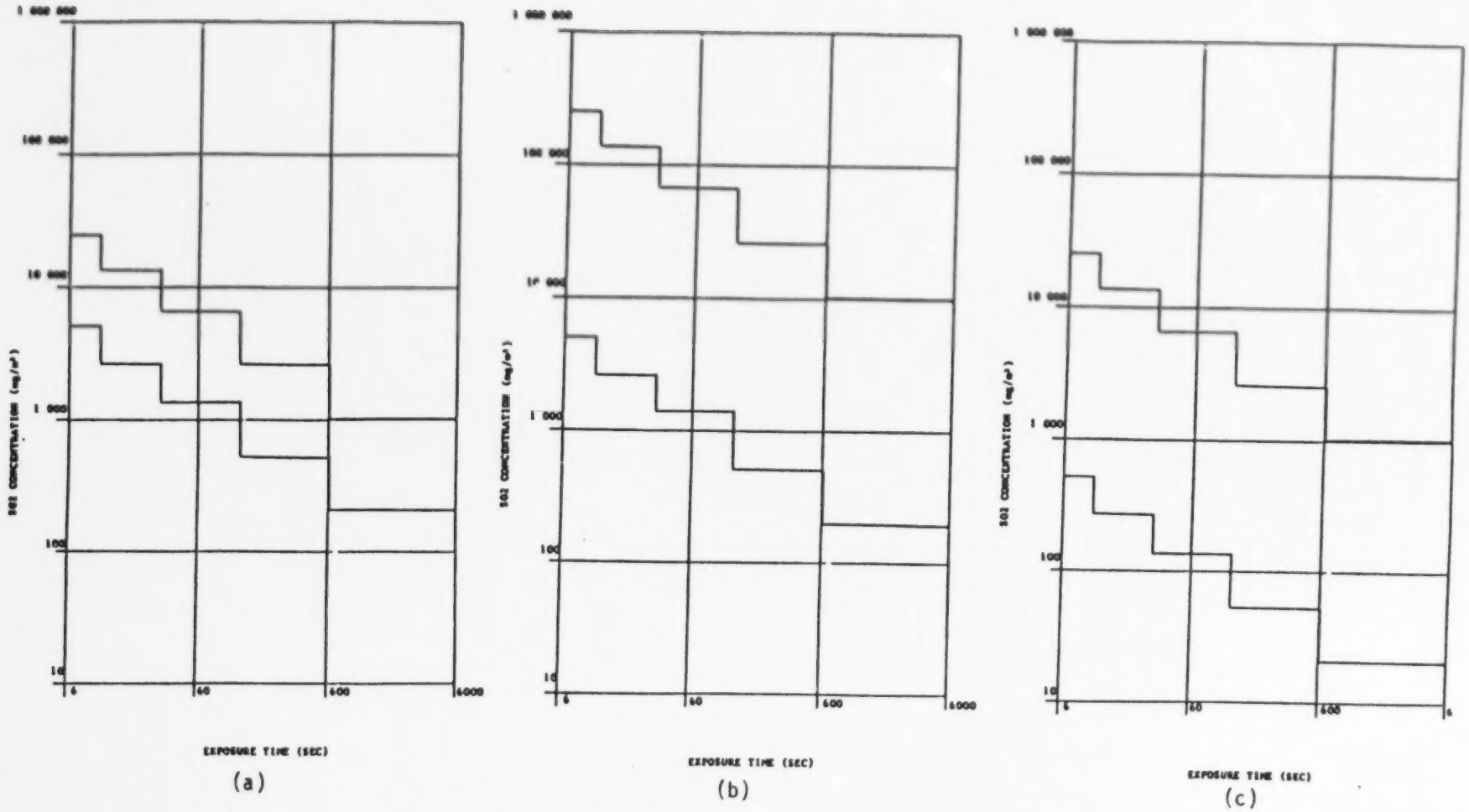
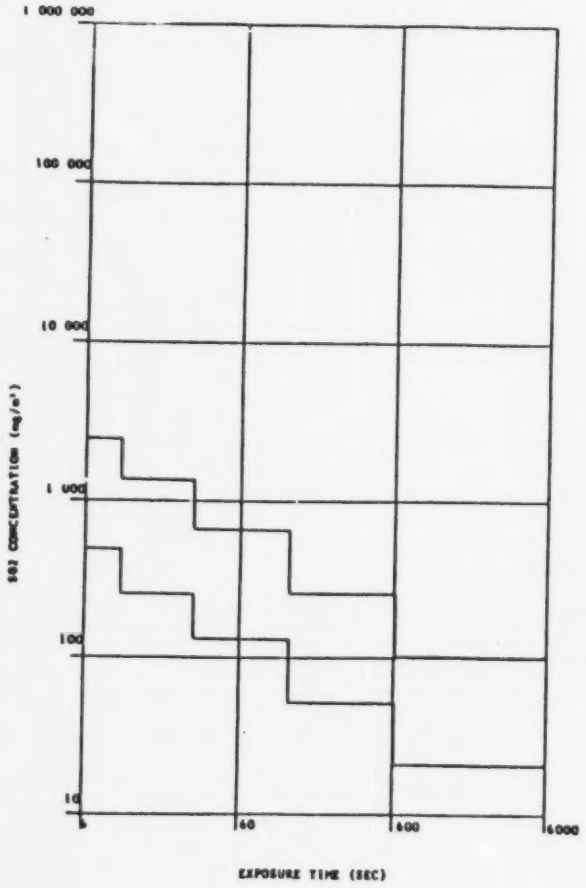
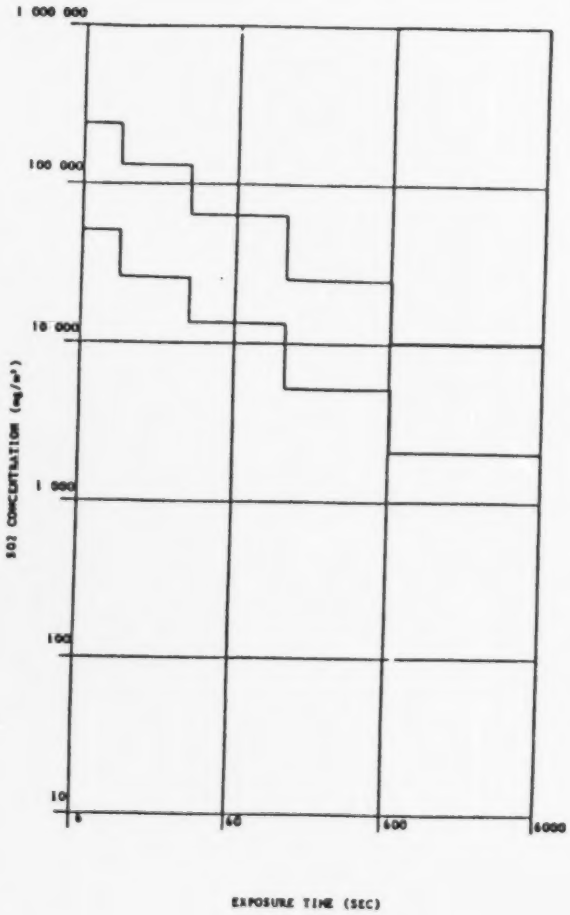


FIGURE 2: SO2 LETHAL CONCENTRATION FUNCTIONS



(d)



(e)

FIGURE 2 (cont'd): SO2 LETHAL CONCENTRATION FUNCTIONS

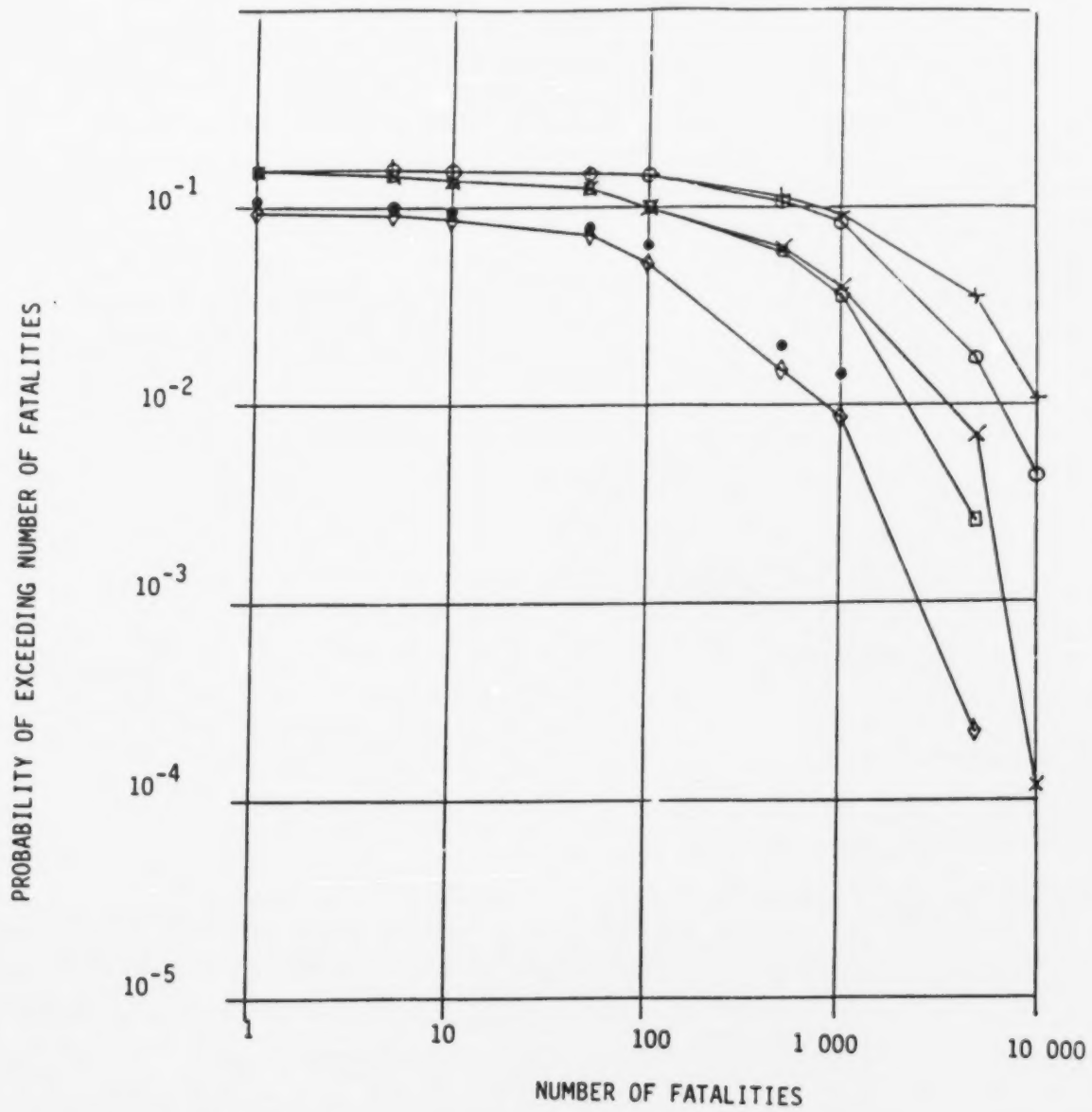


FIGURE 3: RESULTS OF SENSITIVITY ANALYSIS

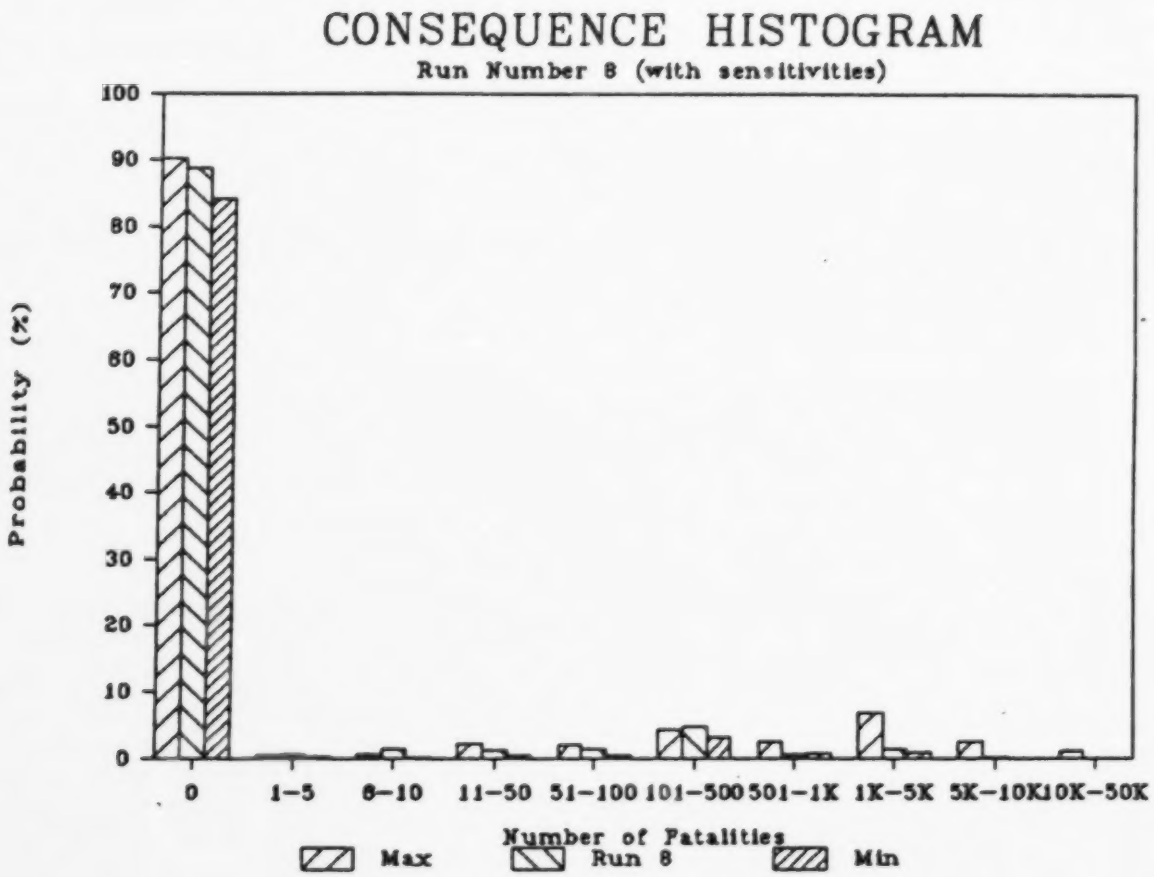


FIGURE 4: CONSEQUENCE HISTOGRAM FOR BURNING RELEASE OF S02 FROM SINGLE-ENDED 1300 MM PIPE BREAK (LOW LEVEL, NO PROCESS TOWER ISOLATION)- SHOWING "ERROR BANDS" FROM SENSITIVITY ANALYSIS.